TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 135

MEASURING AN AIRPLANE'S TRUE SPEED IN FLIGHT TESTING.

By W. G. Brown.

April, 1923.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 135.

MEASURING AN AIRPLANE'S TRUE SPEED IN FLIGHT TESTING.

By W. G. Brown.

For the ordinary range of flying where the pilot never knows the exact velocity and direction of the wind, the airspeed meter serves more as a stability indicator than it does as a true instrument of navigation. The pilot depends upon it as he depends upon the sound of the interplane wires or the stiffness of the controls to tell in what part of the flying range the airplane is operating. Except possibly in navigating over the sea where the winds are steady and can be allowed for, an error of a few miles per hour is of no great consequence.

In competitive performance measurement or full scale scientific research a more exact knowledge of speed is necessary. Since many of the airplanes in use during the war were equipped with airspeed meters, of the Pitot or Venturi type it became common practice to carefully calibrate these instruments and to use their corrected readings for scientific purposes. Toussaint* in France, and Tizard** in England developed similar methods for determining true speed in performance testing which with modifications are still in use today. Briefly, their methods consist in dividing the airspeed meter error into three parts: (1) The

* Notes on Methods and Calculations for Static Tests and Full flight Performance Tests for New Military Airplanes, by Captain Toussaint, Chief of the Service of Tests of the S.T.Ae, 1918.

** Lecture before the Royal Aeronautical Society, 1917, by Tizard.

error of the gage in transmitting the pressure difference produced by the tube into speed under standard and ideal conditions; (2) the error due to variations of the density from the standard for which the instrument is calibrated; and (3) the error due to the particular location of the airspeed meter head on the airplane.

The first error is determined by calibration in the laboratory. The second is computed from the observations of pressure and temperature during the test. The third is the residual error determined by timing the airplane over a known distance, and is by far the most difficult to determine precisely.

Unfortunately, since the airplane flies through the air its speed must be observed relative to the air and not relative to the ground, or if observed relative to the ground a correction must be made for the amount by which the airplane's speed is reduced or augmented by the wind.

To the writer's knowledge five distinct methods shown in Figs. 1-5, have been used for timing an airplane over a given distance and getting a measure of the wind velocity and hence the true speed of the airplane. Fig. 1 shows a straight course laid out along the prevailing wind direction. The airplane is flown first with and then against the wind and the true airplane speed is taken as the average of speed in the two directions. The time over the course may be observed from the ground, the time of passage over each end observer being communicated to the other end electrically, or the observation may be made from the airplane using a pendulum sight.

Fig. 2 shows a course marked by two parallel lines.* The pilot holds his airplane on a compass course at right angles to the end lines and flies back and forth as before. If the timing is done from the ground each end station may consist of two parallel wires stretched one above the other so as to enable the observer to sight the airplane at the instant it passes through the vertical plane containing the wires. The average of the speed in the two directions gives the airplane speed regardless of the wind direction.

A third type of speed course which has become very popular is triangular in shape (Fig. 3). The speed of the airplane can be determined from the ground speed measured on each side of the triangle by the simple diagram shown above the figure.

In England, France and Germany the speed course has been somewhat displaced by a method of locating the position of the airplane at regular intervals of time by means of triangulation, (Fig. 4). Two cameras,** camera obscuras,*** plane tables with mirrors and sights**** or recording theodolites***** as the case may be, are placed at opposite ends of a base line and simultaneous records of the orientation and elevation of the air-

* Preliminary report of Free Flight Tests, by E. P. Warner and F. H. Norton, N.A.C.A. Report No.70.
** Flight Path Analysis with the Aid of Photographometry, by Richard Katzmayer, Motorwagen, January 31, 1920.
*** A Method of Measuring the Speed of an Airplane at a Height, by the Director General of Military Aeronautics, R&M No.266.
**** Notes on Methods and Calculations for Static Tests and Full Flight Performance Tests for New Military Airplanes, by Captain Toussaint, Chief of the Service of Tests of the S.T.Ae, 1918.
***** Speed Measuring Stations. See catalog of Recording Theodolites of Carl Bamberg and accompanying literature.

plane made from each point. By this means the exact location of the airplane relative to a point on the ground can be determined at all times. In order to determine the effect of the wind on the airplane's ground speed, flights can be made with or against the wind or in three different directions, or simultaneous observations can be made on the movement of the air as shown by the smoke puff of a pistol fired from the airplane.

A fifth method now used by the U.S. Navy Department (Fig. 5) has a single samera obscura with the axis of the lens vertical. The airplane flies with and against the wind over the camera, being kept at a constant altitude by statoscope observations. The path of its image on the camera table is followed with a special pencil which automatically marks off second intervals of time as determined by an electric chronometer. While the image of the airplane is in the middle part of the camera obscura field a photographic film covered by a focal plane shutter is passed over the image and a photograph taken. The photograph of the airplane is scaled and the ratio of the image dimension to the dimension of the airplane gives the scale factor for determining the speed of the airplane. This method is easier to manipulate than the triangulation method but like the triangulation method makes it possible to determine the airplane speed at fairly high altitudes where the winds are more likely to be steady.

The accurate timing of an airplane flight over a given distance relative to the earth is a matter of refinement of methods and apparatus. The correction of the flight speed for the wind is uncertain due to the variability of the atmospheric motions. So great is the variation in wind velocity along the path of the airplane and between successive flights that this factor becomes the stumbling block to accurate airplane speed determination by the methods described.

With a view to increasing the accuracy of speed measurement the Flight Test Section of the National Advisory Committee for Aeronautics devised a method by which the measurement of an airplane's true speed is made independent of the wind. It is a well known fact that a Pitot-static tube of proper design when pointed into the wind measures the relative wind speed with extreme accuracy according to the formula* $V = \sqrt{2 P/\rho}$. When mounted directly upon the airplane as in common airspeed meter practice, the speed indication may be in error due to two causes (1) yaw of the tube to the relative wind, an effect which is most noticeable in the static pressure produced by the tube** and (2) the interference of the airplane upon the air flow around the tube, usually considered to diminish the relative wind velocity at the tube.

In the N.A.C.A. method both these causes of error are removed by mounting the Pitot static head on the front of a small trailing bomb suspended some distance below the airplane (Fig.6). The bomb is provided with a stabilizing tail which always points

* At high airspeeds the formulas are modified to take account of the compressibility of the air.

** Some Experiments on Measurement of Static Pressure by the Wind Channel Staff of the R.A.E., R&M No.672.

it directly into the wind. The Pitot and static pressures are transmitted to a gage or to a recording airspeed meter in the cockpit by two rubber tubes attached to the supporting cable. In practice this trailing Pitot-static tube is lowered by the observer 25 or 30 feet below the airplane although it has been found in actual test that it can be drawn up to within 10 feet of the fuselage before any interference can be detected. With this device it is possible to calibrate the regular airpseed meter installed in an airplane with greater accuracy than ever before or if the investigation for which the airspeed is desired involves steady flight the trailing Pitot tube can be used throughout the test for the direct measurement of speed.

Another point which has been gained is simplicity of operation. With the old method more or less complicated apparatus was required and cooperation and sometimes communication between the pilot and one or more observers on the ground was necessary. Moreover, flying was limited to a small altitude range over a definite locality and could only be carried out in especially steady winds. With the new method the speed can be determined in a very short time by pilot and observer, or pilot alone if a drum is provided for lowering and raising the trailing tube. The test can be made over any place or at any altitude at which the air is reasonably smooth.*

As stated, the tube position error or installation error as

* In gusty air the trailing tube is not steady relative to the airplane. Also if damped an airspeed meter of this type reads high in fluctuating winds since the pressure produced by the tube is proportional to the average of the squares of the instantaneous velocities rather than the square of the average velocity.

it is frequently called, has been determined as the difference between two quantities. The precision with which one of these quantities could be obtained was frequently of the same magnitude as the installation error itself so that very little consistent information was obtained regarding the way in which the error was influenced by variables such as speed, pressure and temperature. If, for instance, an airspeed meter was calibrated at low altitude and its installation error determined for that density it was not definitely known that the same installation error could be applied to measurements made at high altitudes. During the summer of 1922, tests were made at Langley Field in which the installation error of a Mark IVA tube installed on the outboard strut of a VE-7 airplane was determined over a range of density from 100% standard to 75% standard.

Two calibrated airpseed gages were mounted in the cockpit and connected to the Mark IVA tube and a trailing Pitot static tube. Readings of these gages were taken over a speed range of 57 - 95 M.P.H. at ground level and also at 10,000 ft. altitude. The differences in the corrected readings of the gages, representing the installation errors of the Mark IVA tube expressed in terms of indicated airspeed, are plotted in Fig. 7. While the points are somewhat scattered due to irregularities in the gages and due to yaw of the airplane to the relative wind, it is apparent that the installation error expressed in this way is independent of the air density.

Further tests were made on a JN4h airplane similarly equipped with a Mark IVA head and trailing Pitot static tube to determine as far as possible the cause of the installation error. In these tests very sensitive pressure gages were connected between the respective static tubes and pressure tubes of the two heads. The information obtained is given in the following table.

Indicated Airspeed M.P.H.	Engine R.P.M.	Difference in Pitot pressures Inches of water*	Difference in Static pressures Inches of water*	Installation correction Inches of water	Installation correction in terms of indicated airspeed M.P.H.
40	1300	0	-.07	-.07	-1.8
62	1320	0	-0.12	-.12	-2.0
80	1550	-.005	-0.17	-0.17	-2.2
80	Throttle closed.	0	-0.12	-0.12	-1.6

The installation correction on the JN4h appears to be of the same magnitude as on the VE-7. The observations show that the installation error is wholly due to a suction produced by the static tube. Since a Mark IVA tube tested in the wind tunnel** shows a similar error when yawed between the angles of 6° and 12° we may conclude that the installation error for any airspeed meter installation similar to the ones tested is probably wholly due to the yaw of the tube. If there was any appreciable change in relative velocity at the tube due to the interference of the airplane wings, it would be apparent in the Pitot tube pressure.

* Positive of trailing Pitot-static pressures are greater than Mark IVA pressures.

** Rapport A 20, Verslagen en Verhandelingen Van Den Rijks - Studiedienst Voor de Luchtvaart. Amsterdam, 1921.

This means that a swivelling Pitot static tube of the type used in all N.A.C.A. accelerated flight tests (Fig. 8), may be expected to have a very small or negligible installation error. It is apparently not important to mount the tube on a long pole in front of the wings as has been frequently done.

Referring again to the stationary tube, we should expect the installation correction for a given speed to vary with variations in angle of attack caused by different inclinations of the flight path. This was actually found to be the case, the installation correction for the JN4h at 80 M.P.H. changing from 2.2 to 1.6 on closing the throttle and nosing down. Thus it appears that unless the tube is made to swivel or is otherwise made independent of yaw errors,* the installation error is a function not only of the airspeed but also of the engine speed.

In conclusion, it seems proper to discuss briefly the characteristics of different airspeed meter tubes which do or do not recommend themselves for flight testing. Venturi tubes used in a variety of combinations have been popular in France, Germany and the United States, probably because they provide large pressure differences and make possible the use of robust gages. All these tubes are, however, subject to the fault of being very critical to slight changes such as may occur in manufacture or be caused by corrosion or abuse. Furthermore, it appears that the Venturi tube does not follow any simple equation connecting suction, velocity and air density but follows a more complicated

* Some experiments on Measurement of Static Pressure by the Wind Channel Staff of the R.A.E., R&M No.672.

equation involving a function of the Reynolds number.* The Pitot tube, on the other hand, can be modified considerably without deviating from the simple theoretical impact formula.** Pitot static tubes and especially ones mounted in such a way as to permit them to swivel have been used in the National Advisory Committee's flight tests for a period of nearly two years and except in one respect, the allurement which they offer wasps for nesting places, they have been found most satisfactory for speed measurement.

* The Altitude Effect on Airspeed Indicators, by M. D. Hersey, F. L. Hunt and H. N. Eaton, N.A.C.A. Report No. 110.
** Rapport A 20, Verslagen en Verhandelingen Van Den Rijks - Studiedienst Voor de Luchtvaart. Amsterdam, 1921.

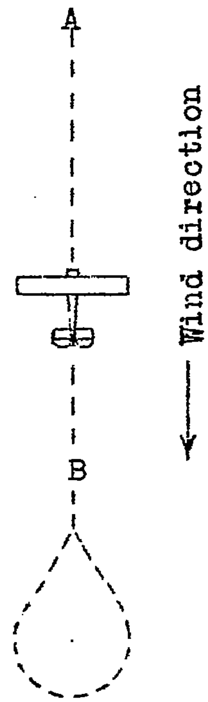

Fig.1

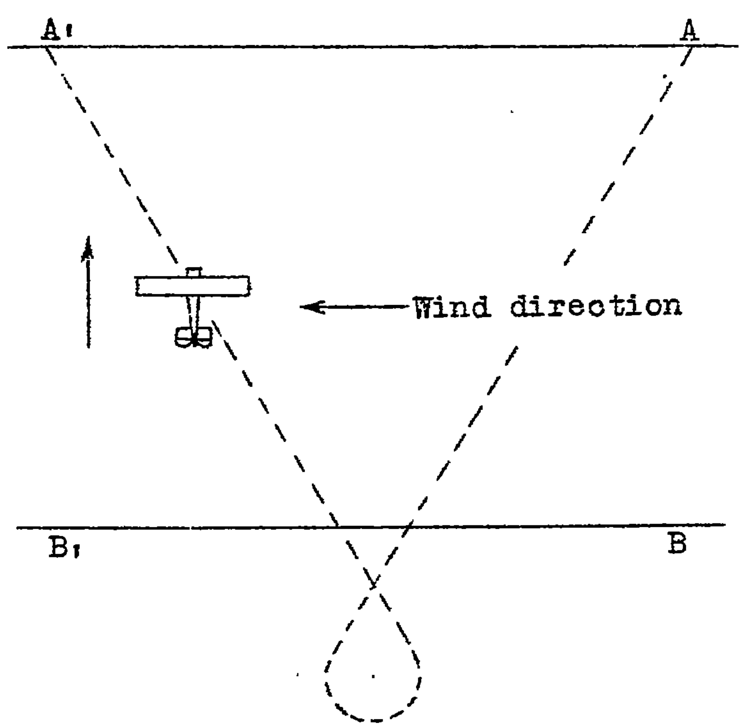

Fig.2

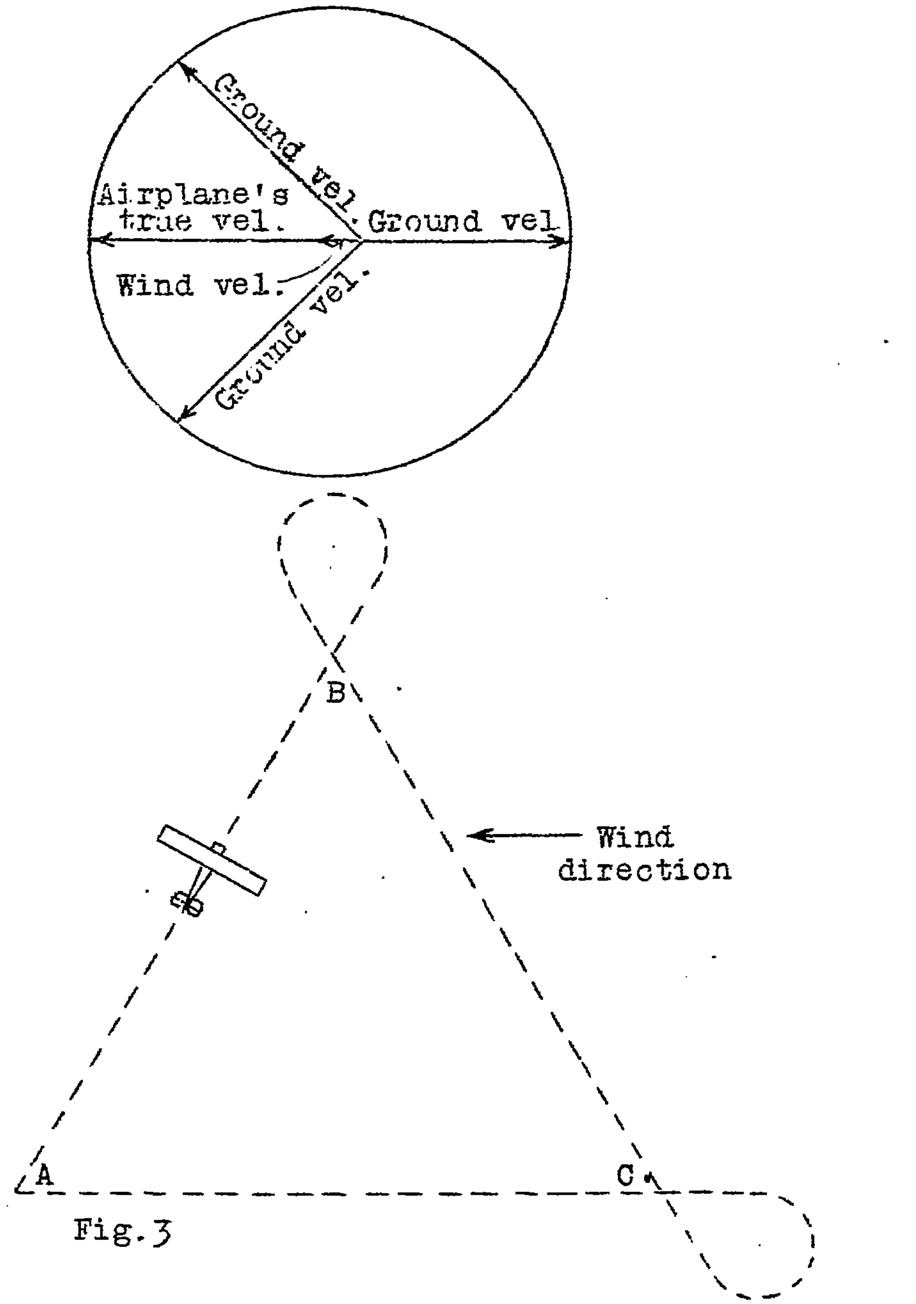

Fig.3

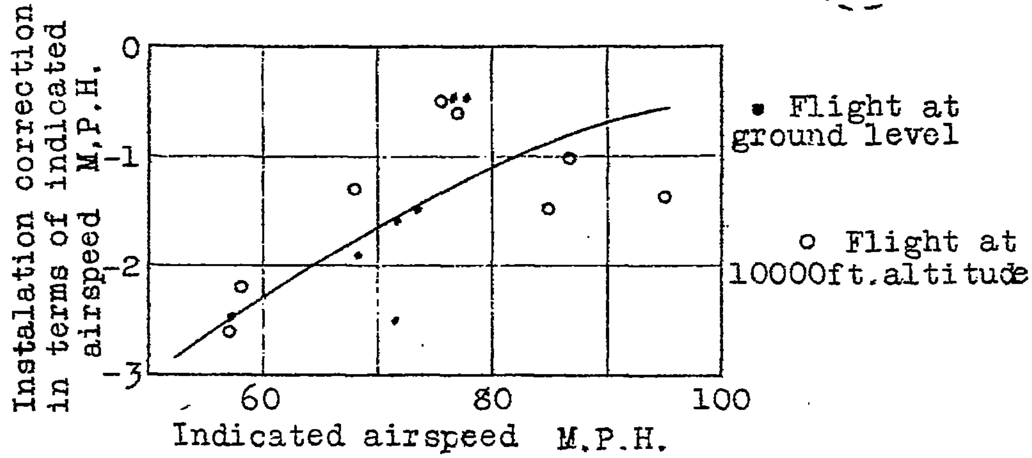

Fig.7 Installation correction for Mark IVA Head on VE-7 airplane.

Figs. 3&7

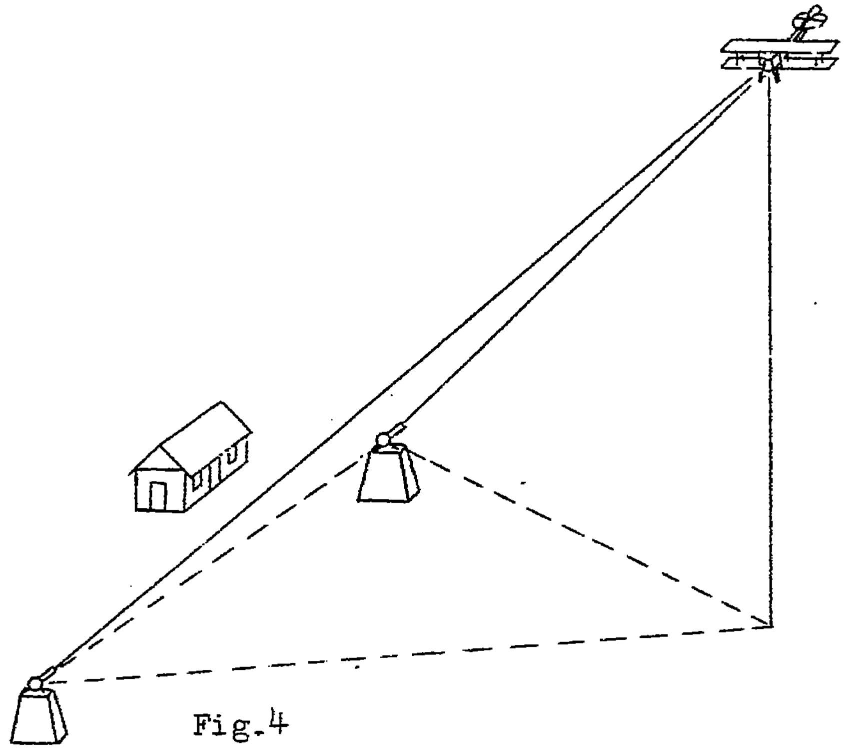

Fig.4

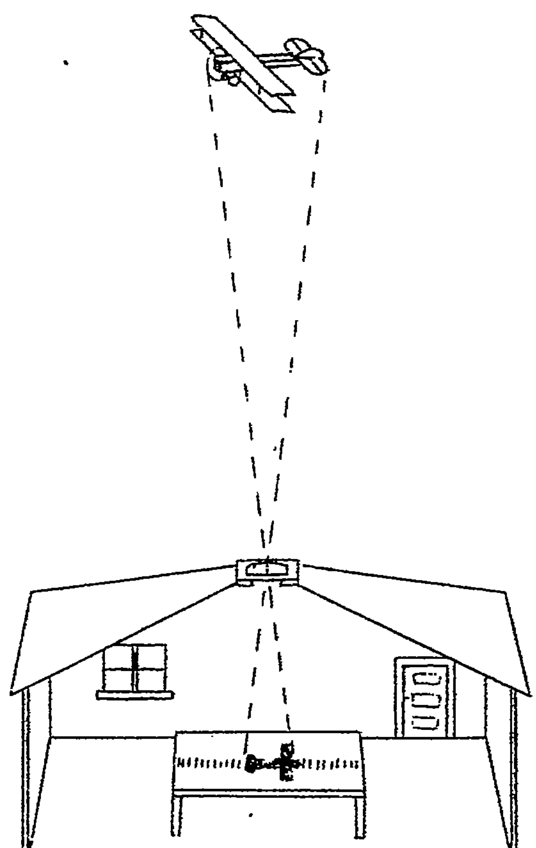

Fig.5

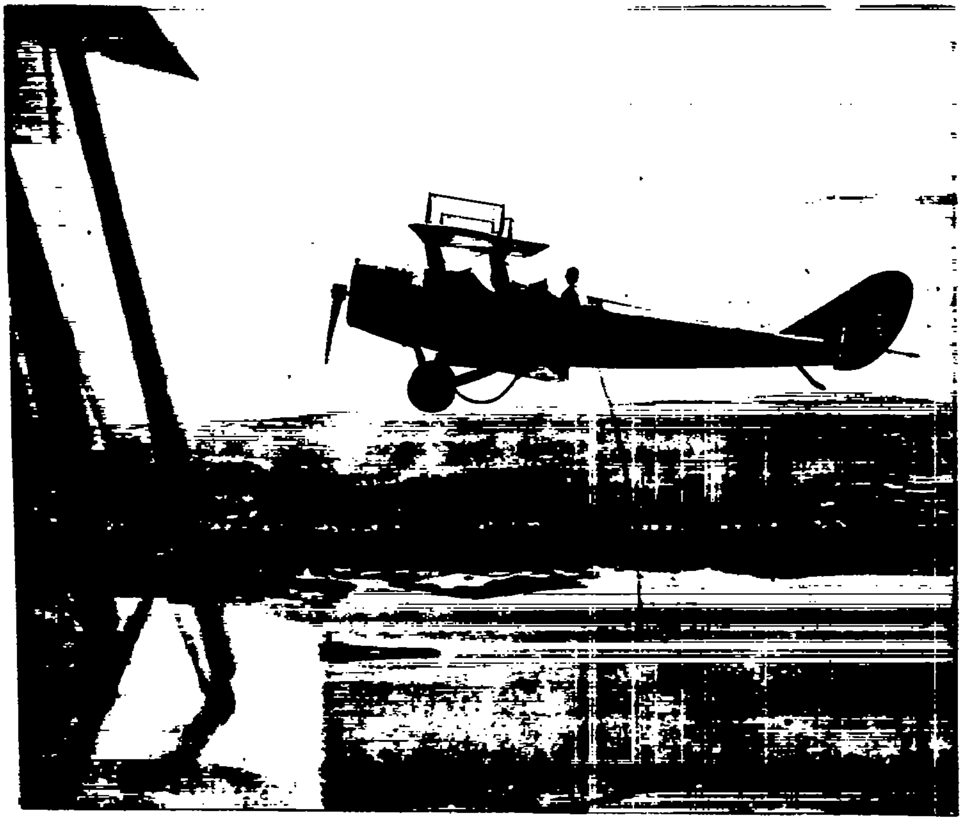

Fig. 6

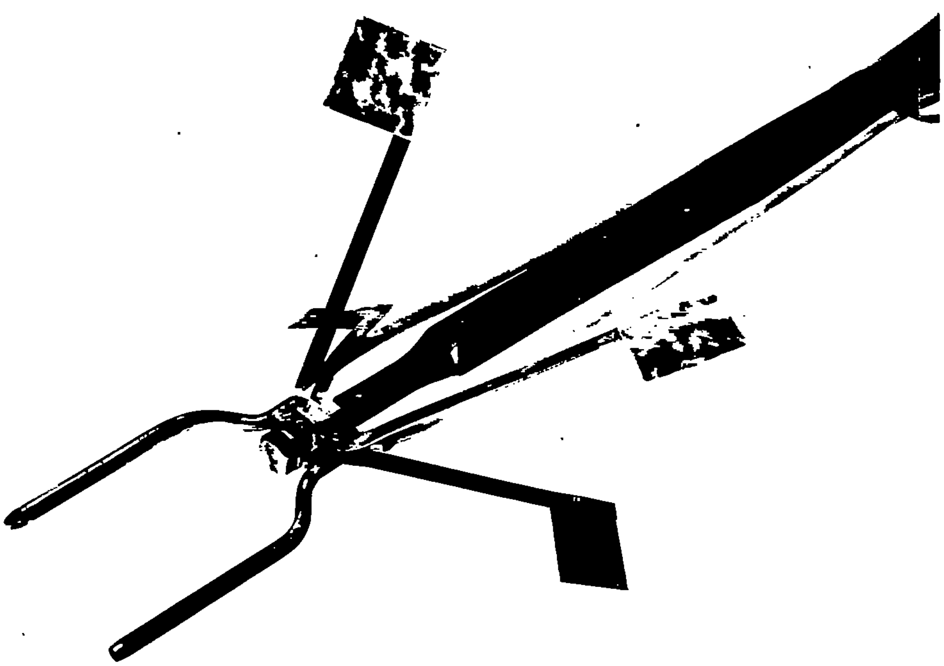

Fig. 8

10865 A.S.